Chapter 4
Planning

4-1. Regulatory Requirements

In the past 10 years, a number of chemical grouts have been removed from the market because of toxicity problems. For example, use of acrylamides and similar material was banned in Japan a number of years ago after several cases of contamination of drinking water wells were reported. Precautions must be taken, therefore, when there is the possibility of chemical grouts coming in contact with wells or groundwater or where the presence of a chemical grout could cause problems at some later time. Even seemingly innocuous materials can have harmful results, such as affecting the pH of groundwater. It is essential that before work is begun, all possible harmful effects of chemical grouting be ascertained. In addition, all applicable laws, regulations, and restrictions must be reviewed thoroughly. Not only should Federal statutes be reviewed but also those of states, cities, and other government entities.

4-2. Preliminary Planning

The planning of a chemical-grouting program consists of procedures similar to those for any other grouting operation. Planning involves establishing the purpose for grouting, obtaining a description of the job, determining the field conditions, performing the necessary field sampling and testing, conducting a laboratory program to reveal the characteristics of the material to be grouted, and determining the suitability of the various chemical grouts to satisfactorily complete the job. After these items are completed, personnel, field procedures, and equipment required can be established.

a. Background information. Certain background information is needed to determine the feasibility of chemical grouting. This includes:

(1) A description of the problem that is being addressed. This includes a quantitative assessment of the degree of strength required or the need to reduce water flow.

(2) Results of drilling and sampling in the area to be treated, delineation in terms of geologic strata and their thicknesses, and extent with respect to surface locations and varying water-table elevation to include determination of groundwater elevations and gradients. Drilling and sampling are performed to determine the location and nature of the zones that might require additional grouting and to permit a preliminary estimate of the type or types and quantities of grout required. The information desired is determined by laboratory or field tests on samples judged to be representative of the zone from which they were obtained.

(3) Data on characteristics of the medium to be grouted, such as particle size and permeability (Table 4-1).

(4) Chemical composition of groundwater and of the medium to be grouted.

Table 4-1
Approximate Soil Properties

Soils[1]	Grain Size, mm, Approx	Permeability cm/sec	Void Ratio[2]	Porosity[3]
Gravel and coarse sand	0.5 and over	10^{-1} and over	0.6-0.8	0.375-0.45
Medium and fine sand	0.1 to 0.5	10^{-1} to 10^{-3}	0.6-0.8	0.375-0.45
Very fine sand and coarse silt	0.05 to 0.1	10^{-3} to 10^{-5}	0.6-0.9	0.375-0.5
Coarse and fine silt	0.05 and less	10^{-5} to 10^{-7}	0.6 up	0.375 up

[1] Additional information on other media is given in para 4-3a.
[2] The volume of voids with a soil mass divided by the volume of solids.
[3] The volume of voids divided by the total volume.

(5) Determination of the permeability of the in situ soil or rock. The general geology of the area should be known, specifically, in fractured rock, the size, configuration, and location of openings; coatings on the surface of the openings (which may affect bonding); amount of free water or moisture present (which may also affect bonding); and the strength of the medium to be grouted (which may affect grouting pressures employed).

(6) Information about the strength that can be developed in grouting fractured rock or concrete to establish whether chemical grouting will be a satisfactory approach. In some circumstances, tests may be required to show that sufficient strength can be developed to justify using the more expensive chemical grouts rather than cement grout. The openings in the fractured medium must be sufficiently large and, for the most part, well-connected to permit injection of the grout. The selection of a particular chemical-grouting system normally requires laboratory tests.

(7) Evaluation of cementitious versus chemical grouting (pros and cons of each for the site).

b. Factors affecting grouting operations.

(1) Certain factors affect grouting operations, and data regarding these factors should be obtained as follows:

(a) Physical characteristics of medium to be grouted.

(b) Temperature, both ambient and in the area to be grouted.

(c) Physical and chemical properties of grout solutions.

(d) Compatibility of chemical grout properties with physical, chemical, biological, and regulatory environments at the site.

(e) Grout hole size and spacing.

(f) Methods of drilling and cleaning.

(g) Methods of grout application.

(2) The chemistry of the medium to be grouted and of the mixture and groundwater probably influences chemical grouting more than any other factor. Chemical and physical analyses should be made of the material to be grouted and of the mixture water and groundwater prior to field grouting. Tests of the mixture water will indicate its suitability for the particular system being used (i.e., effect on gel time, strength, etc.); tests of the groundwater will indicate its effect on the grout after injection. Most chemical grouts can be formulated to meet specific requirements if the makeup and approximate quantities of the chemicals in the medium and water are known.

(3) Among the properties of chemical grout solutions that materially affect injection are the initial viscosity and the viscosity throughout the injection period; however, performance, not viscosity, should be used as the final criterion for selecting one grout over the other.

(4) The method of drilling is an important factor affecting grout injection. Drilling with circulating water in the hole will remove cuttings from the hole and keep the hole walls flushed of cuttings that would otherwise form occlusions during grouting. Clean drill holes are essential in grout rock.

c. Additional information. Information that may be helpful in planning and executing chemical-grouting operations includes the following:

(1) In dry granular materials, gravitational and capillary forces act to disperse injected grout, and the extent of this dispersion may be sufficient to render the gel ineffective. Excavations in test areas are needed.

(2) Granular materials below the water table can probably be more effectively stabilized than a dry mass.

(3) The decrease in permeability of rocky soil after stabilization depends upon the resistance of the gelled grout to extrusion from the pores in the mass. If penetration into a granular mass is appreciable, the gel cannot be extruded from pores at pressures less than the pumping pressures required to place the solutions; the pumping pressure should always exceed the static water head at the point of placing.

(4) Groundwater will displace grout in the direction of flow. In uniform formations of fine-grained materials, the rate of groundwater flow is generally so small that its effects will be negligible for most injection rates. Short gel times should be used, for instance, in medium-to-coarse sands where there is or is suspected to be an appreciable groundwater flow. Where the rate of groundwater flow is appreciable, a gel time as short as possible with a pumping rate as high as possible consistent with pressure limitations should be used. The chances of a

successful job are lessened if the rate of groundwater flow exceeds the rate at which grout can be placed.

4-3. Laboratory Testing

Laboratory tests should be conducted prior to commencing any field operations including small-scale field tests. This will eliminate delays in completing the job. In some instances, it may be advisable to conduct certain tests not necessarily dictated by the immediate problem in the event unusual situations arise. Laboratory tests include those for compressive strength, permeability, and gel time.

a. Selection of a chemical grout.

(1) In the selection of a chemical grout, it should be kept in mind that chemical grouts are generally more expensive than portland-cement grouts; however, some of them will develop a greater tensile strength, a better bond, and a higher compressive strength, depending upon the medium being grouted. Chemical grouts generally have the ability to penetrate smaller openings than cementitious grouts; however, special care should be taken in selection because of the cost. Consideration should be given to performing the grouting operation by employing a combination of alternating or concurrent cementitious and chemical grouting, if possible, for economy reasons. Also, from the standpoint of economy, cementitious grout should be used in lieu of chemical grout where possible.

(2) The physical properties of the medium to be grouted need, in some instances, to be known and matched as closely as possible. For instance, some chemical grouts bond poorly to wet or moist surfaces. The bond to wet or moist surfaces would probably be no greater than bond through the grouted mass and would probably be weaker because of dilution of the chemical grout at the interface or incompatibility of the grout with moisture.

(3) Cracks in concrete as narrow as 0.05 mm have been grouted with chemical grout, whereas portland-cement grouts are usually limited to use in 1.5-mm or larger openings. Cracks as small as 0.7 mm are also reported to have been grouted with a neat portland-cement grout. It has been reported that the lower limit for neat portland-cement grout penetrability is no finer than the 600-µm sieve. Figures 4-1, 4-2, and 4-3 and Table 4-2 show comparisons of grout types with respect to penetration characteristics, a viscosity-percent concentration

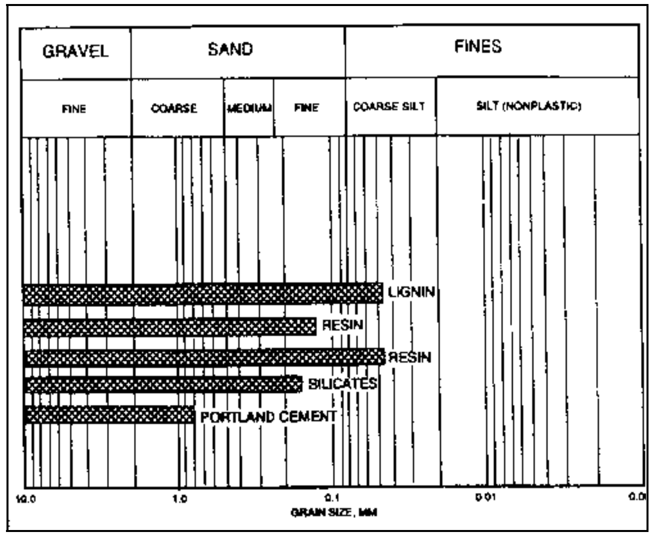

Figure 4-1. Comparison of methods for stabilizing soils and relative penetration ability

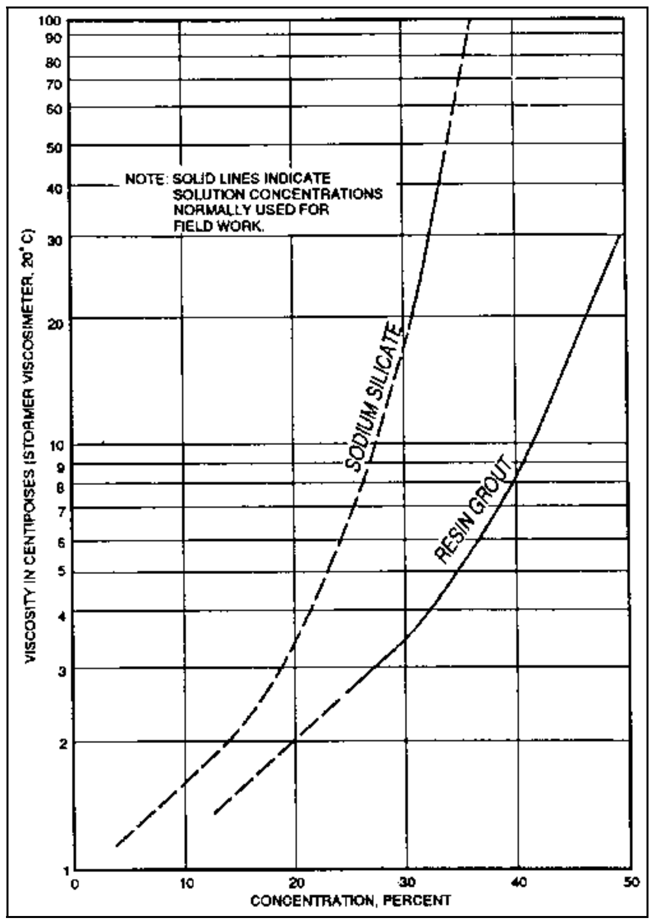

Figure 4-2. Viscosities of various grouts

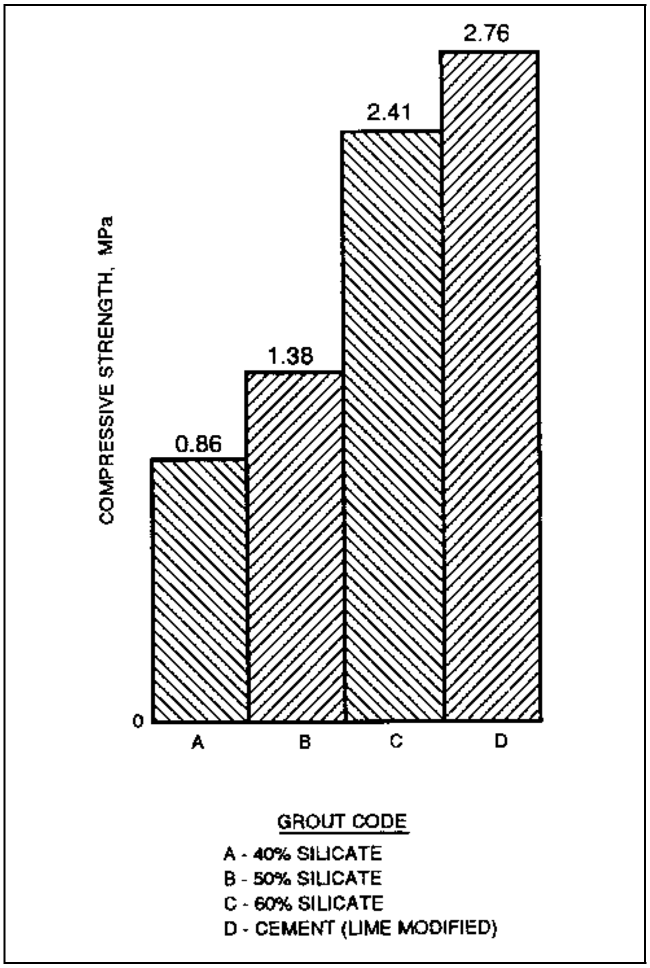

Figure 4-3. Comparison of compressive strengths of chemical grouts injected into medium-fine, wet compacted sand, injected and cured wet (adapted from Raymond International, Inc. 1957)

relation, a comparison of compressive strengths, and physical properties of chemical grouts, respectively.

b. Grouting patterns.

(1) Normally, several injection pipes or locations are used to inject chemical grout. The grouting pattern involves both the location of the pipes and the order in which the grout is placed. General criteria dictate that the sequence of injections should be performed so that the area initially grouted confines the areas to be treated by subsequent treatments, a minimum of two circles of holes are generally required for complete overlapping in circular patterns dependent upon hole spacing and the material being grouted, and three rows of holes are generally required for complete overlapping for linear patterns such as cutoff walls.

(2) In the grouting of granular materials, the injection locations should be based on the average diameter of a stabilized column, computed from the volume to be pumped and the void ratio (Figures 4-4 and 4-5). A distance slightly less than the average diameter should be used as the grid spacing. This spacing arrangement should satisfactorily seal even pervious strata. Injection pressures for the final injection should be anticipated to be higher than those required for previous work.

(3) When stratified deposits are grouted, a minimum of three rows of injections is generally required so that the confining effects of adjacent stabilized masses force subsequent injections into less pervious areas. Short gel times should also be used. With short gel times, the gelation occurs below the bottom of the pipe at all elevations, which eliminates the possibility of pumping all the solution from one injection into one stratum because the gel time and the location of the bottom of the pipe are known. The gel times need to be adjusted for changing pipe elevations.

c. Factors influencing injection methods. The material to be grouted influences the injection method to be used. Packers cannot be used satisfactorily in formations that are not competent and that will not maintain an open hole. In this instance, the formation itself acts as a seal to

Table 4-2
Physical Properties of Chemical Grouts

Class	Example	Viscosity cPs	Gel Time Range min	Specific Gravity	Strength kPa
Silicate (low concentration	Silicate-bicarbonate	20	0.1-300	1.02	Under 345
Silicate (high concentration)	Silicate-chloride	4-40 30-50	5-300 0	1.10 --	Under 3,450 Under 3,450

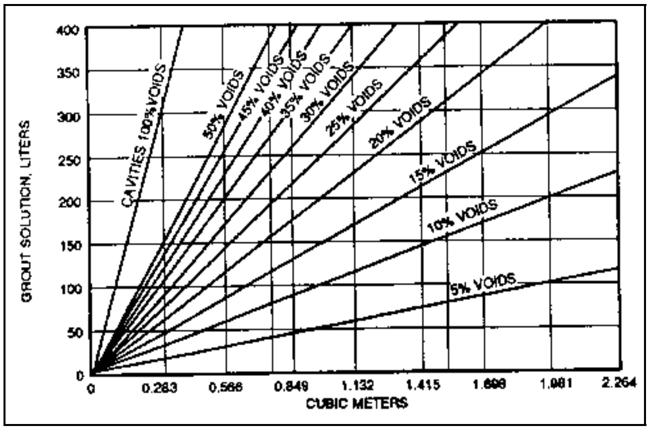

Figure 4-4. Stabilized volume in grouted medium related to grout volume (adapted from Raymond International, Inc. 1957)

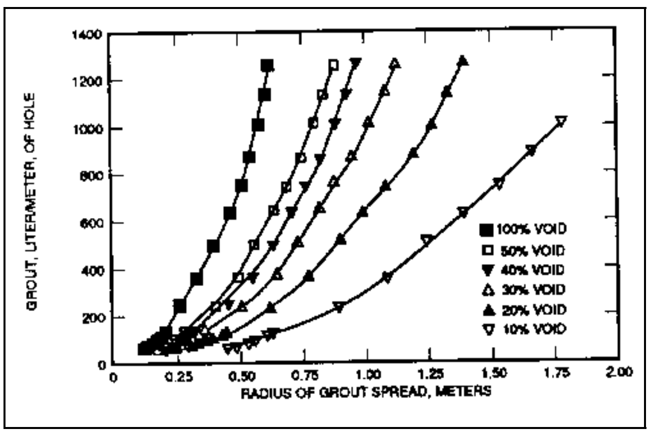

Figure 4-5. Penetration related to grout volume and percent voids (adapted from Raymond International, Inc. 1957)

prevent grout from returning along the path of the injection pipe. However, if a packer is required in an unstable open hole, the location at which the packer is desired may be grouted to form a fast-setting grout plug, the plug drilled to be a diameter to accommodate the packer, and the packer subsequently emplaced downhole at this location. Where formations will maintain an open hole, various arrangements of packers may be used.

d. Estimating quantities.

(1) In estimating chemical quantities and costs for a grouting operation, the physical dimensions of the volume of medium to be grouted and its porosity or void ratio can be used to compute the volume of grout needed for an application. Computations are most likely to be inaccurate because of the use of erroneous void ratios. The following points should be considered when establishing values of void ratio:

(a) Granular, noncohesive deposits will have, depending upon the relative density, void ratios generally between 0.6 and 0.9.

(b) Cohesive deposits will not generally accept grout.

(c) Silts of an organic nature may not accept grout.

(d) In some deposits, only the coarser strata or pockets may accept grout.

(e) In fractured rock formations, only the larger channels may accept grout. The actual fractional volume of voids should be adjusted to the percent voids that will accept grout for the purpose of computing grout volumes (Figures 4-4 and 4-5). Grout volumes for a particular job should also include a contingency for waste and dilution.

(2) When grouting through a hole where the grout pipe is to be raised or lowered at intervals, the volume of grout per specified length should be computed so that this information, in conjunction with the void ratio, can be used to compute the size of the grouted mass. Viscosity of the grout affects the time-rate of spread from one hole.

(3) Figure 4-4 shows grout quantities required to fill various void contents and is based on total fill. However, this ideal situation of total fill is seldom reached, and, as an example, it has been determined that 330 to 440 L/m^3 is an approximate quantity for injection into unconsolidated granular materials with about 35-percent voids, such as medium to fine sand.

(4) Figure 4-5 can be used in calculating quantities of grout for grouting in vertical holes.

e. Cost.

(1) The cost to prepare a given volume of chemical grout solution will vary with the different chemical grouts and the concentration of ingredients used. Three factors used to compute a cost estimate for purchasing include a total known volume, a known groutable void ratio, and a certain chemical concentration.

(2) Figures 4-4 and 4-5 can be used to estimate not only volume but also cost.

f. Economic considerations.

(1) Economic considerations in chemical grouting include the initial cost of materials, location of jobsite, quantities of grout to be used, type of materials (liquid or powder) to be shipped, and volume to be placed. Generally, the more grout that is used, the lower the unit price. Labor, overhead, and equipment rental are other influencing factors as well as the cost of drilling the grout holes.

(2) In the event an open hole remains after chemical grouting, the hole could be backfilled with a portland-cement grout mixture, which would, in most instances, somewhat reduce the overall cost. Portland cement and sand are usually available at most construction sites.

4-4. Field Operations

a. Field procedures.

(1) An important aspect of field planning is the selection of specific techniques for use. A technique for cutting off surface backflow in shallow placement operations uses a short gel time in combination with controlled on-and-off pumping cycles. Unfortunately, short gel times may also result in gel formation in areas that would seal off the mass being treated against further treatment. When surface backflow is first observed, the pumps are kept running until it is certain that the material produced is true chemical grout. Dyes can be helpful in distinguishing the chemical grout from water or some other solution. The grout running out at the surface is checked for gel time, and the gel time of a new solution is shortened. The pumps are then shut off for a length of time equal to half that of the gel time. When the pumps are turned on again, if backflow reoccurs, the pumps are kept running until sufficient chemical has been pumped to clear the pipe or hole, and the pumps are then shut down for a length of time equal to three-fourths that of the present gel time. When pumping is again resumed, if seepage starts again, the procedure is repeated, but the pumps are restarted at a lower rate. In order to use this method without plugging the hole, the actual gel time must be known.

(2) Gel times shorter than pipe-pulling time have been successfully used. This is of benefit in stratified deposits where pumping pressure limitations permit and also where following water is present. Gel times as short as practical should be used to prevent the grout from being carried away by groundwater and to seal more pervious areas, thus forcing grout into the finer material. Injection efficiency in stratified deposits would naturally be decreased with a gel time increase in this instance.

(3) The desired results of a field grouting program are most readily obtained if the size and shape of a grouted mass can be predicted. Heterogenous stratification and flowing groundwater modify the end result.

(4) Grout injected from a point within a mass of uniform permeability, as in a sand mass, can be expected to flow out from the injection point to form a sphere. This is normally true if the grout injection pressure is greater than the static head and if the volume is small so that the hydrostatic pressures at top and bottom of the mass are not significantly different. The rate at which grout is placed, the rate of groundwater flow, and the gel time determine the displacement and final configuration of the grout mass.

(5) Injected grout will seek the easiest flow paths. The only factors that can be introduced to modify this condition are control of the setting time and, in some instances, a change in viscosity. Accurately controlling the gel time is also important in stratified deposits. If the permeability between the horizontal and vertical directions differs due to either placement or stratification, as is frequently the case, better control can be obtained if the grout is formulated to set up at the instant when the desired volume has been placed where water may be flowing. With gel times shorter than pumping times, the grout pumped last is farthest from the injection point by virtue of being forced through previously gelled grout. If the location of this point is known and if the grout gels at this location, then the grout mass location is known.

(6) After a grout or grouts have been selected, a small-scale field test should be performed as a final step in deciding which grout to use.

b. Physical properties. In general, granular materials or rock masses with overall permeabilities of 1×10^{-7} cm/sec or less cannot be economically grouted. Included in this category are clays, very fine silts, and coarser materials containing sufficient fines to render them relatively impermeable. Formations with permeabilities of 1×10^{-5} to 1×10^{-7} cm/sec can be grouted, generally with difficulty, particularly where the formation is shallow and limited pumping pressures can be used. Noncohesive soils in this permeability range are generally classed as silts. Coarser materials with higher permeabilities can generally be grouted without difficulty.

Successful grouting of materials with low permeabilities depends primarily upon the grout selected.

c. Changes in physical properties. Chemical grouting may either harm or improve the original properties of the grouted material. Chemical grouting of granular materials may serve a dual purpose: improvement of existing properties and alteration of existing properties to form a new material. In the latter case, the chemicals in the grout react with grouted material to form a new material. The new material may or may not be an improvement. Adverse effects of chemical grouts on materials may possibly include an increase in permeability or a decrease in strength. Cyclic drying and wetting or all drying may be detrimental to a grouted area because of a breakdown of the gelled chemical grout brought about by the cycles.

d. Dilution. In general, dilution with groundwater is detrimental only when the dilution is such as to bring a quantity of grout below the concentration at which it will gel. This will occur when turbulence exists, or is created, or when a small volume of grout is injected into a large volume of flowing water and to a lesser degree of static water. These conditions are sometimes checked by the use of dye tracers to determine the extent of the dilution and the effectiveness of countermeasures. Generally speaking, water-based chemical grouts will dilute to varying degrees depending upon the conditions mentioned above.

e. Penetration. Grouts that have a viscosity of 2 cP will penetrate at half the rate of water (1 cP) at equal pressure or require double the pressure to obtain rates equal to that of water. Thus, viscosity differences are significant in the range approaching the viscosity of water. Other conditions being equal, the rate at which chemical grouts can be pumped into a formation will vary inversely with the grout viscosity and directly with the pumping pressure.

4-5. Grout Availability

Chemical grouting is a rapidly changing field due to both technological and regulatory advances. New products are being introduced onto the market, and older products are being withdrawn. In order to determine what is currently being offered by vendors, it is necessary to consult trade and industrial directories and current periodicals and technical journals. The best sources of current data are the manufacturers, suppliers, and their most recent clients.